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NEOPLAN ARTICULATED BUS
STRUCTURAL STUDY

Prepared for the
Transportation Development Centre
Transport Canada

October 1982

By
T E S Limited
Ottawa, Canada

The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre of Transport Canada.

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17 Abstract

A City Liner 116 articulated inter-city bus manufactured by Neoplan Gottlob Auwärter GMBH, under in-service investigation on a joint program between Voyageur Incorporated and the Transportation Development Centre, experienced structural failure of some main members of the articulating joint. A test program, consisting of laboratory and field examinations, was conducted to investigate the cause of failure and the suitability of the repairs and modifications carried out.

The probable cause of failure was determined to be cyclical stress reversal applied to the structural members by normal bus motion. The repairs and modifications increased the strength of the structure to the point where repetition of the loading conditions should not result in failure.

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17 Résumé

Ce rapport présente les conclusions du programme d'essais en laboratoire et sur le terrain lancé à la suite de la rupture d'éléments majeurs de l'articulation d'un autocar "City Liner 116" de la firme Neoplan Gottlob Auwärter GMBH, exploité à titre expérimental dans le cadre d'un projet pilote mené conjointement par Voyageur Inc. et le Centre de développement des transports. Ce programme d'essais visait à déterminer la cause de la rupture et à évaluer les réparations et les modifications faites pour que cela ne se reproduise plus.

Le rapport établit comme cause probable l'inversion cyclique des contraintes subies par ces éléments en cours de fonctionnement normal. Il note aussi que les réparations et modifications faites ont eu pour effet de renforcer les éléments défectueux de façon telle qu'aucune rupture ne risque de se produire sous l'action, même répétée, des contraintes précédemment mises en cause.

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SUMMARY

The following report describes the investigation of the repairs and modifications to the structural members of a City Liner 116 inter-city bus. The bus is under in-service investigation by Voyageur Incorporated and the Transportation Development Centre while it operates from the Montreal terminus.

Severe failure of a number of the main structural members of the rear section of the articulating joint caused the bus to be removed from service. Repairs and modifications to the structural members were performed based on drawings supplied by the manufacturer, Neoplan Gottlob Auwärter GMBH, and on further adaptations designed by Voyageur personnel.

A test program was conducted to investigate the cause of failure and the suitability of the repairs and modifications carried out. The program included examination of the failed structural members which had been removed during the repair work, discussions with Voyageur personnel familiar with the failure, and review of the suggested modification drawings provided by Neoplan.

The test program was designed and conducted to measure stress levels in the modified structural members under operating conditions, to determine the probable cause of the failure, and to assess the suitability of the repairs and modifications, in order to determine if the failure of the structural members would be likely to occur again in normal service.

An area in the vicinity of the attachment points of the support beams of the rear section of the articulating joint was chosen for extensive testing. The area was chosen based upon an assessment of the modified design and knowledge of the area which failed in the original design.

Stress analysis tests were carried out during on-road trips around the Ottawa area, with and without passengers. Strain gauges were mounted on and around the support arms, based on the direction and location of the cracks in the previous failure of the support arms. All strain gauges were connected to appropriate indicators which permitted the strain output voltages to be recorded.

The test results indicated that all measured stresses were well below the endurance limit for the structural members. Therefore, the modifications made to the structural members were determined to have successfully reduced stress levels such that these members should not fail in normal service.

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Figure 1 Neoplan Articulated Bus

1. INTRODUCTION

1.1 Background

Voyageur Incorporated and the Transportation Development Centre are currently conducting an in-service evaluation of a City Liner 116 inter-city articulated bus manufactured by Neoplan Gottlob Auwärter GMBH. The bus has been operating in regular service from the Montreal terminus. Recently, severe failure of a number of the main structural members of the rear section of the articulating joint caused the bus to be removed from service.

Repairs and modifications to the structural members were carried out based on drawings supplied by Neoplan, with further adaptations designed by Voyageur personnel. Before the bus was returned to regular service, it was desired to investigate the possible effects of the repairs and modifications, in order to determine whether the articulating joint was liable to fail again in the future.

As a result, T E S Limited was contracted under TDC Contract No. 4769 in July 1982, to perform the work as detailed in this report.

1.2 Objectives

The project objective was to test the performance of Voyageur's Neoplan articulated bus and diagnose the cause(s) of the problems requiring recent repairs.

1.3 Scope

The project included an examination of the failed structural members which had been removed during the repair work, discussions with Voyageur personnel familiar with the failure, review of the suggested modification drawings provided by Neoplan, design and conduct of a test program to measure stress levels in the modified structural members under operating conditions, a diagnosis of the probable cause of the failure, and an assessment of the suitability of the repairs and modifications carried out, in order to determine whether failure of the structural members would be likely to occur again in normal service.

2. DESCRIPTION OF THE PROBLEM AREA

As can be seen from Figure 1, the Neoplan bus is constructed in two sections with an articulating joint between them. Power is transferred to the ground via the tandem axles at the rear of the front section. Steering is accomplished in the normal manner by the front wheels, with an additional linkage to the extreme rear axle so that its wheels also steer. The articulating joint allows a limited amount of rotation about the vertical and transverse horizontal axes (yaw and pitch), but does not allow for any rotation about the longitudinal horizontal axis (roll). The reason for this can be seen in Figure 2, which gives a stylized drawing of the main components of the articulating joint.

The lower portion of a turntable, which allows yaw motion, is fixed to the front section of the bus. The upper half of this turntable has a large transverse beam with two bearings mounted on it. These bearings support transverse pins which are fixed to the rear section of the bus, thus allowing pitch motion. The pins are mounted at the forward ends of two cantilever support beams which project forward from the main frame of the rear bus section. The failures under investigation took place at the points where these two cantilever beams were joined to the main vertical frame members of the rear bus section.

In the initial construction, the cantilever beams were butted against a transverse frame member and welded to it. Additional support was provided by adding gussetting underneath the beams to join them to vertical frame members. The cantilever beams themselves were hollow box sections. The transverse and vertical frame members were dual box sections. Figure 3 shows a view of the failure in the gusset area where it attaches to the vertical frame member. The cantilever beam has been cut away, however the photograph shows the small piece of square box cross section remaining at the point where it was welded to the transverse frame member. The twin box construction of the transverse frame member can also be seen. The sketch in Figure 4 provides further orientation to aid in understanding the features shown in Figure 3.

In the modified design, the cantilever beams were strengthened by using a boxed-in wide flange section, and were extended to the rear, past the transverse frame member, in order to better transfer any loading to the frame. Also, angled lateral support beams were added. Figure 5 shows a side view of the right hand side of the modified articulating joint, with the rear bus section to the left, the right hand cantilever beam running across the middle of the picture (with its lateral support arm in the left foreground) and the turntable visible in the lower right corner.

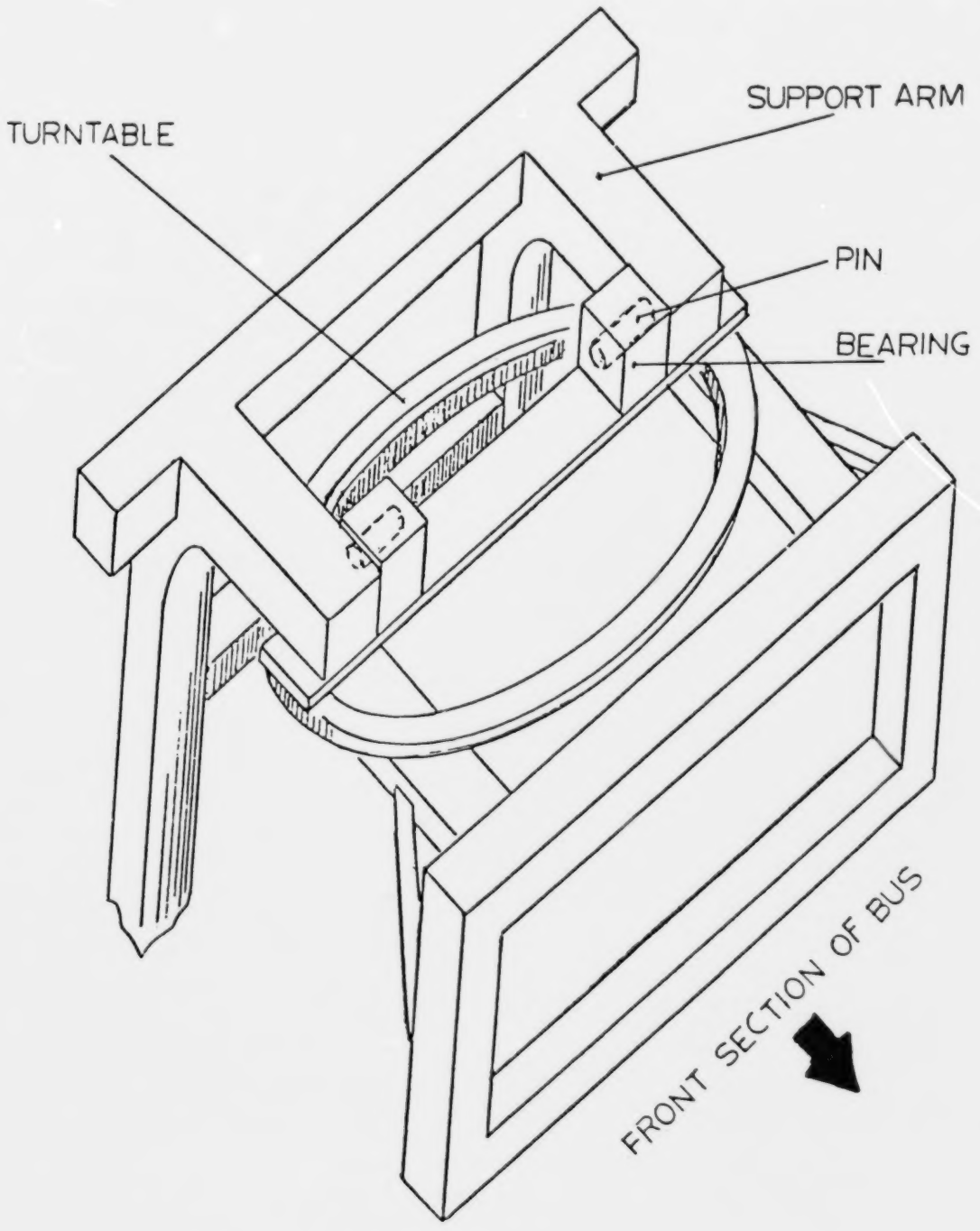


Figure 2 Schematic Drawing of the Articulating Joint

Figure 3 View of One of the Failed Members

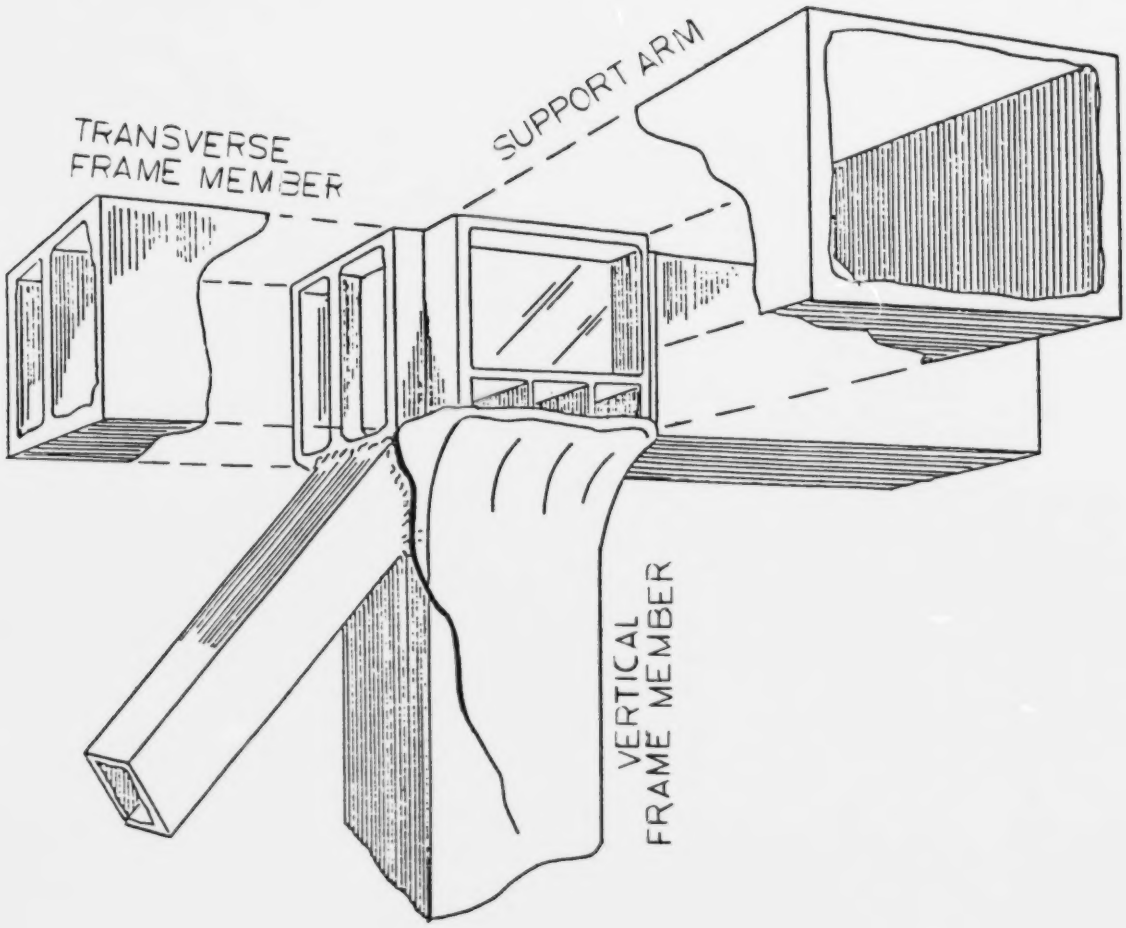


Figure 4 Sketch of the Area of Failure

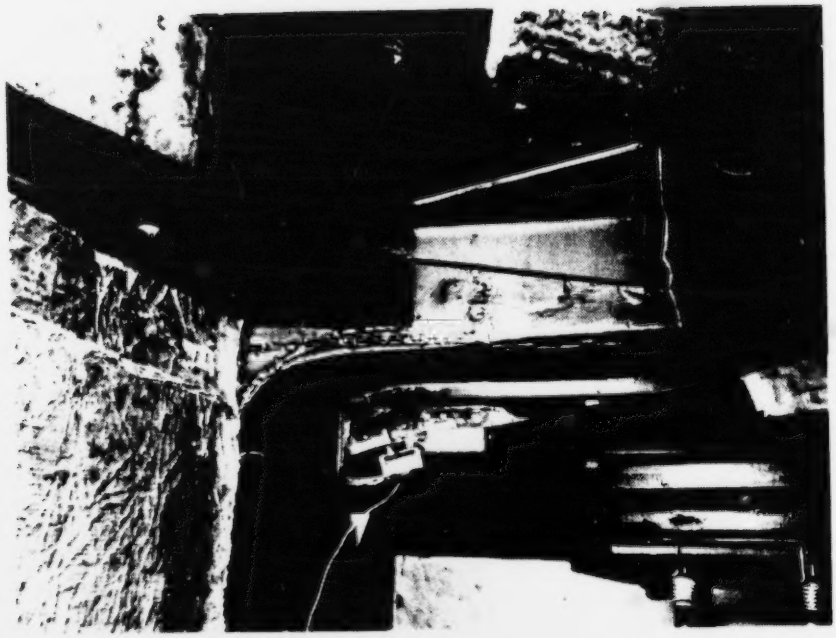


Figure 5 View of the Modified Beam Arrangement

3. PROCEDURE

3.1 Initial Investigations

In order to gain an appreciation of the problem, the T E S Limited project team reviewed the history of the failure of the structural members with Voyageur personnel. In addition, the failed parts which had been removed were examined, as were the drawings of suggested modifications provided by Neoplan. Finally, the modified structure was examined in conjunction with Voyageur personnel, and the general mode of operation of the bus was reviewed.

3.2 Theoretical Calculations

Prior to actual testing, a number of calculations were performed to predict the stress levels likely to be found in the structural members under investigation, namely the two cantilevered support beams of the rear section of the articulating joint.

The bus was first weighed by section, and measured, in order to allow calculation of the action and reaction forces at the pins located at the forward ends of the cantilever beams.

The values obtained were then used to calculate maximum stresses to be expected in the locations planned for two strain gauges. In this way the validity of experimental readings to be obtained could be readily verified.

3.3 Strain Gauge Tests

Based upon a preliminary assessment of the modified design, coupled with knowledge of the area which failed in the original design, an area in the vicinity of the attachment points of the two cantilever support arms was selected for detailed testing. This area was thoroughly cleaned with a solvent including as much of the area of the support arms as possible. The load was taken off the support arms by jacking up the rear section of the bus. Bearing support bolts were loosened at the arm pins.

The area under study was then prepared for a Brittle Coating stress analysis by first spraying a coat of Tens-Lac, type U-10-A undercoat and allowing this to dry. The area was then sprayed with several coats of Tens-Lac, type TL-500-70-A Lacquer. Approximately 6 square feet of area was sprayed.

Three calibration bars were also prepared in the same manner as mentioned above. After one day of curing, the load was placed onto the arms and the coating was observed completely for tensile cracks.

Tenslac type TL-500-70-A lacquer, has a threshold strain of approximately 500 μ in/in at 70 F. The threshold strain is that strain value for which the first tensile cracks will appear in the lacquer. Due to the temperature and humidity conditions at the time of testing, the threshold strain was actually 580 μ in/in as determined by testing the calibration bars.

The bus was taken on a short trip around the Ottawa area with no passengers on board. It was put through rigorous turns while travelling forward and in reverse. The objective here was to subject the arms and support areas to some significant stress level, so that tensile cracks would appear in the lacquer.

The support arm and surrounding areas which were lacquer coated were again observed for cracks and no cracks could be detected. This would indicate that there were no strain values greater than 580 μ in/in in the metal that was lacquer coated. It was therefore decided to use a more sensitive lacquer coating in order to try to achieve some cracks in the coating.

Tens-Lac, type TL-500-75-A lacquer was sprayed over the first Tens-Lac coating so that a lower threshold strain could be achieved. The procedure for removing load from the support arms was repeated as before. Also, three more calibration bars were prepared for determining the value of the threshold strain.

Once again, one day was allowed for curing. The weight was placed on the support arms and all coated surfaces were observed for cracks. No cracks were detected. The Tens-Lac type TL-500-75-A lacquer had a threshold strain of 460 μ in/in as determined from testing the calibration bars.

The bus was taken for a short trip again with passengers on board. Similar turns in forward and reverse were done for the bus as mentioned previously. Again the objective was to try to produce cracks in the lacquer. No cracks were observed in the lacquer after this second test.

The next phase of the stress analysis involved the mounting of strain gauges on the support arms and in the vicinity of the arms.

Figures 6 and 7 show 2 views of the support arms and support structure in the vicinity of the arms. They also show the location of sixteen strain gauges mounted to the metal in this area. The symbol "L" was used to indicate the left-hand section and "R" was used to indicate the right-hand section.

Gauges L1 and R1 were located on the top of the arms near the support pins. This is the location for which theoretical stress calculations were carried out. Comparison of measured readings from these gauges with the theoretical values could thus be used to confirm the validity of the readings being taken.

The locations and orientations of gauges L2, R2, L8 and R8 were based on the direction and location of cracks which appeared in the previous failure of the support arms. These gauges were oriented to measure the largest tensile stresses in these areas.

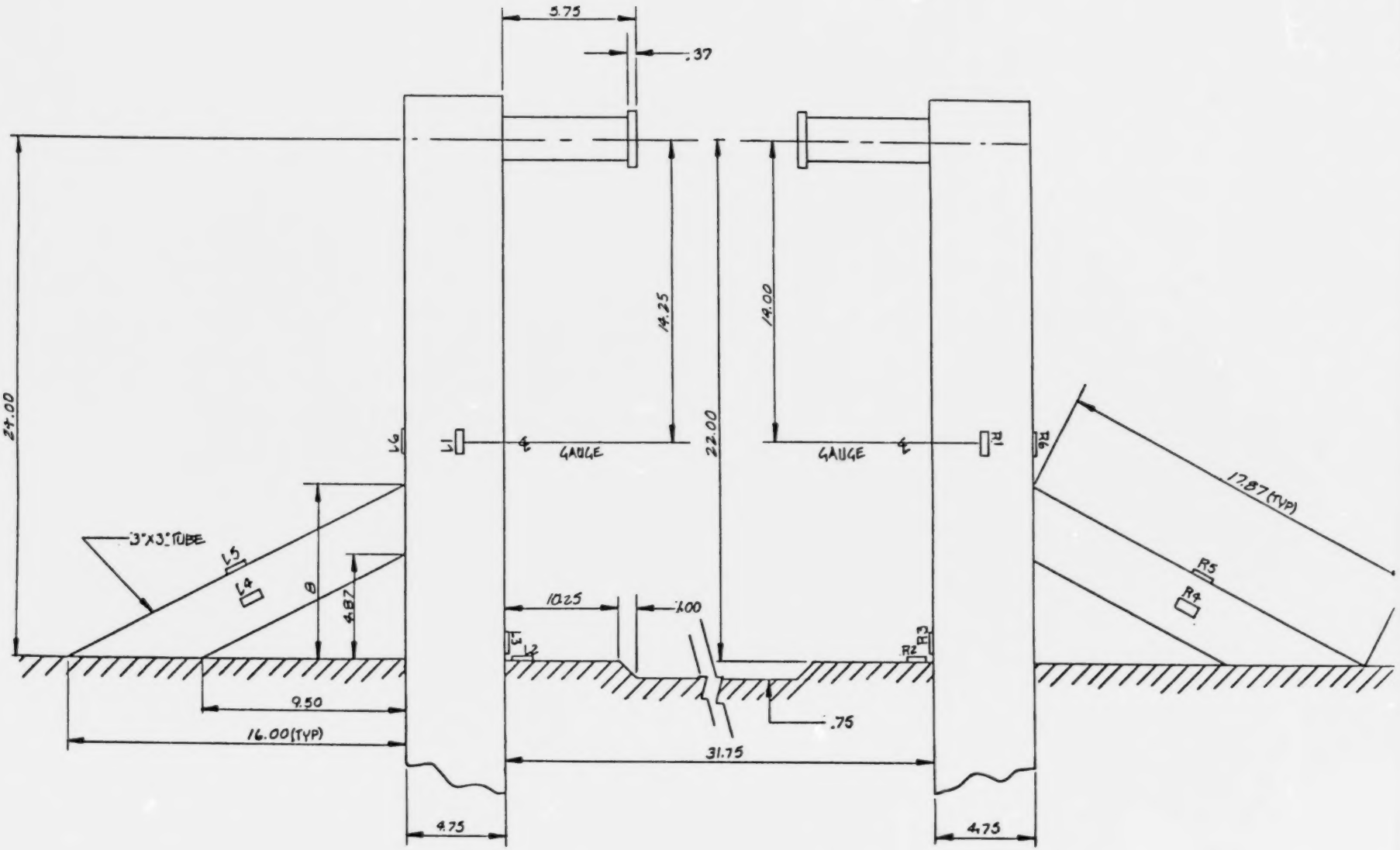


Figure 6 Top View of Support Arms Showing Strain Gauge Locations

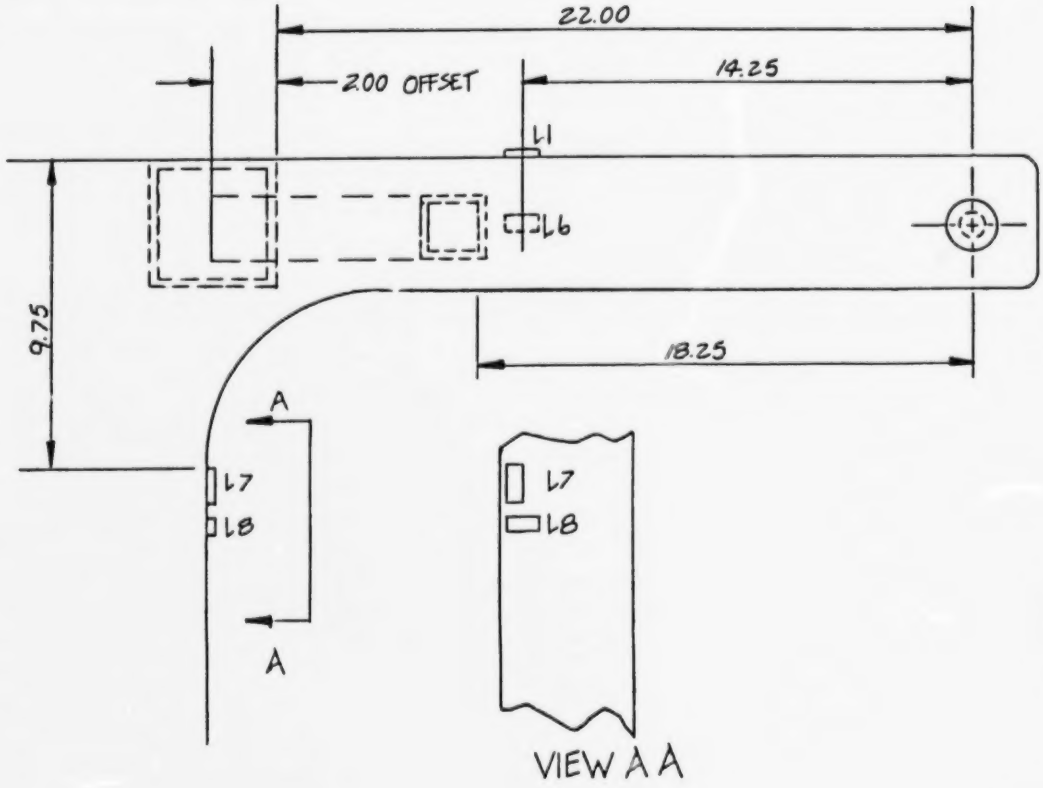


Figure 7 Side View of Support Arm on Left Side Showing Strain Gauge Locations

Gauges L3 and R3 were located on the arms and close to the right angled corners as indicated. They are also mounted close to gauges L2 and R2 respectively.

Gauges L4, L5, R4 and R5 were applied to the 3 x 3 inch square steel tube used to provide horizontal support for the arms. These gauges would check for stresses in this area.

Gauges L6 and R6 were located on the sides of the arms aligned with gauges L1 and R1 so that stresses could be measured, and loads could be determined in the horizontal plane.

Gauges L7 and R7 were located close to L8 and R8 in order to indicate if stresses were high at right angles to the directions of L8 and R8.

All strain gauges were connected to appropriate strain indicators, and switch and balance units, which permitted the strain output voltages to be directed to a 6 channel strip chart recorder. The gauges were Micro Measurements precision strain gauges type CEA-06-250 UW-120.

All gauges mentioned above are called active gauges and these were tied in with appropriate temperature compensation gauges so that no errors in strain readings would result due to temperature fluctuations. The sixteen active gauges were mounted to the support arm area when load was removed from these arms.

The six strain indicators were calibrated using a simple cantilever beam arrangement, with a strain gauge connected to the beam. Various loads were added to the end of the beam and the voltage output was sent to the strip chart recorder. A setting of 50 millivolts per division on the strip chart recorder was found to be a convenient scale. In terms of strain, this permitted a maximum value of approximately 208 μ in/in to be detected on each channel.

With all gauges zeroed, the load was placed on the arms and strain readings were taken for all sixteen gauges.

The bus was then operated for a short distance under no load conditions and strain readings were recorded. When it was established that all systems were functioning correctly, the strain gauge indicators were zeroed, and the bus was loaded with forty-six passengers, twenty in the rear section and twenty-six in the front. The resulting increase in static loading stress values were then recorded.

In consultation with Voyageur personnel, a route was selected between Ottawa, Ontario and Wakefield, Quebec, and the bus was operated in the loaded condition for approximately 150 km. The route chosen was representative of the worst case inter-city roads which the Neoplan bus would encounter in service with Voyageur. Strain gauge readings were recorded throughout the trip.

4. RESULTS

4.1 Initial Investigations

Discussions with Voyageur personnel indicated that crack propagation in the area where the support arms joined the rear vertical frame members had been noticed during routine inspection. An initial attempt was made to rectify the problem by simply welding over the cracked areas. This was unsuccessful, as the cracks began to appear once again. Neoplan was contacted, and supplied a set of drawings, ostensibly to serve as guides to modifying the affected structure so as to prevent further failure. Since these drawings were felt to be insufficient, Voyageur personnel added to the design changes. The initial and final designs were described in detail in section 2 of this report. Details of the crack in one of the failed members and the attempt to repair it by welding, can be seen in Figure 3. A similar crack was evident in the same location on the other support arm.

4.2 Theoretical Calculations

Figures 8 and 9 show the wheel weights measured for the loaded and unloaded conditions, and the resulting action and reaction forces calculated for the articulating joint horizontal pins.

For the calculation of stress at a given location on a beam, we use the formula

$$S = \frac{Mc}{I}$$

where S = stress
M = moment about the point
c = distance of the point from the centroidal axis of the beam
I = moment of inertia of the cross sectional area of the beam

For the cantilever support arms in question, the cross section is a nominal 4 inch wide flange, boxed in with 3/8 inch plate. Details of the calculation of the moment of inertia for this cross section are given in Appendix A. The value arrived at is 32.7 in^4.

For stress in the region of strain gauge L1, assuming that both support arms receive equal loading, and using the empty bus reaction forces calculated as above, we get

$$M = \frac{4378}{2} \times 14.25 \text{ lb. in.}$$

$$c = 2.5 \text{ in.}$$

$$I = 32.7 \text{ in.}^4$$

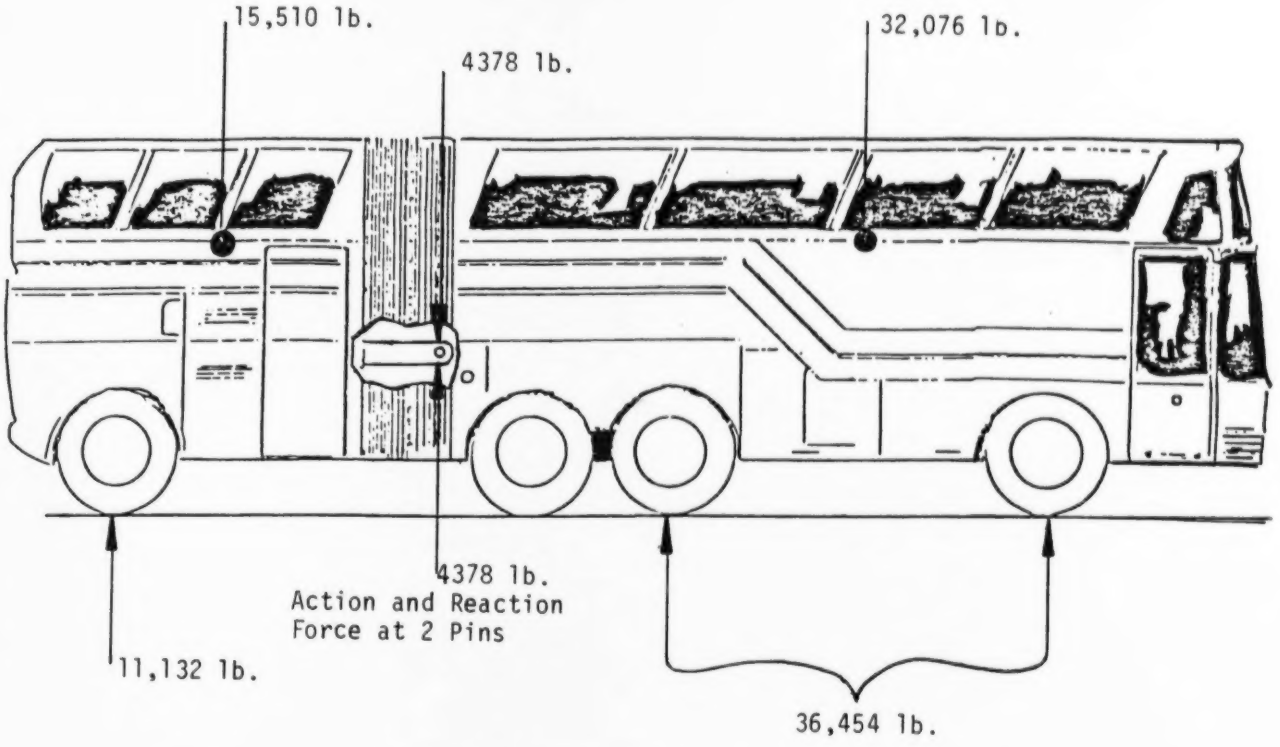


Figure 8 Bus Loading - No Passengers

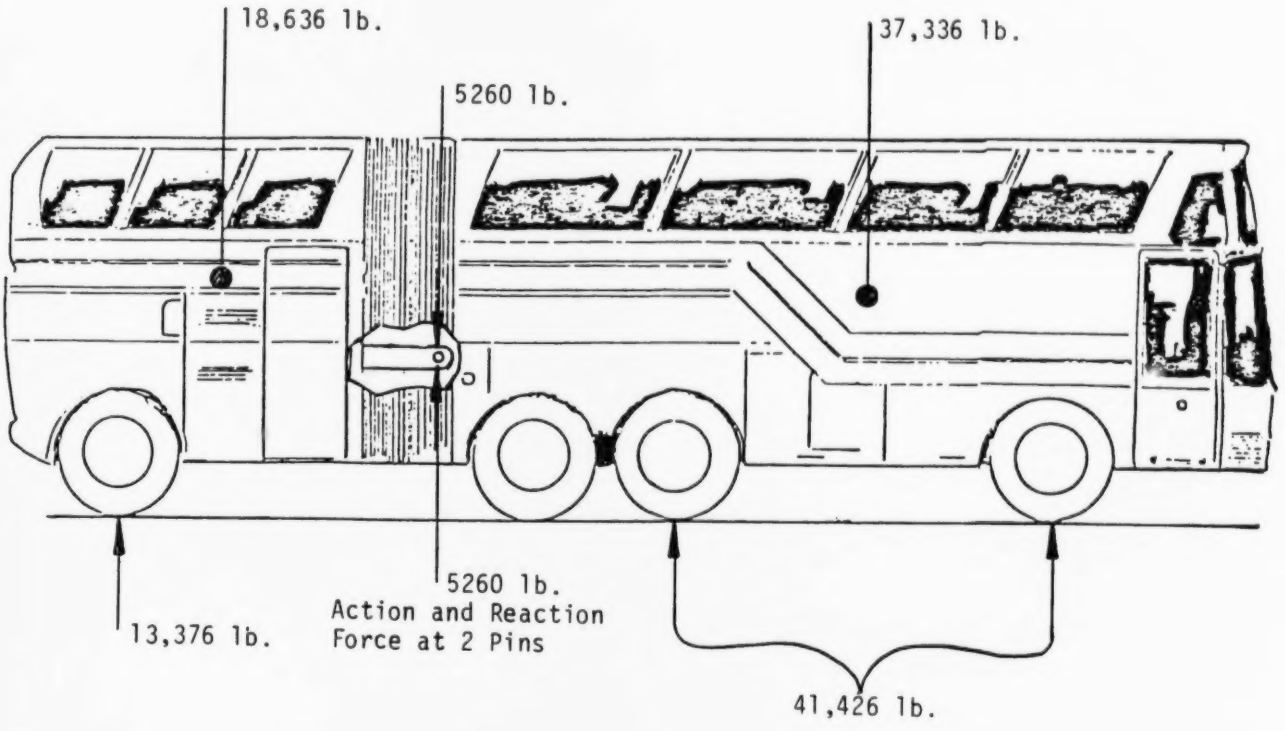


Figure 9 Bus Loading - With Passengers

Therefore stress can be calculated as

$$S = \frac{Mc}{I} = 2384 \text{ psi}$$

This value is in compression as it is on the upper surface of the beam.

For the bus loaded condition, an increase in this stress would be expected, and can be calculated by using the increased reaction force of 822 lb. total which is the difference between the loaded and unloaded conditions. Therefore we get the increased stress at L1 to be

$$\Delta S = \frac{\Delta Mc}{I} = 480 \text{ psi}$$

Therefore we would expect stress values at L1 of 2384 psi in the unloaded case, increasing by 480 psi as the bus is loaded.

4.3 Strain Gauge Tests

For the initial brittle coating tests performed, no cracks appeared in the coating under any conditions which were induced. Since the initial coating had a threshold strain value of 580 μ in/in and did not crack, and the subsequent coating with a value of 460 μ in/in did not crack, we can calculate a maximum possible value for stress as follows:

$$S = \varepsilon E$$

where S = stress
ε = strain
E = Young's Modulus for the metal

for the case under consideration

$$\varepsilon < 460 \text{ } \mu \text{ in/in}$$

$$E = 30 \times 10^6 \text{ psi for steel}$$

$$\therefore S < 13{,}800 \text{ psi}$$

This gives a maximum possible value for the stress anywhere in the tested area.

In the first series of tests with the bus unloaded, the strain readings for all sixteen gauges were recorded with the bus stationary, and are shown in Figure 10.

This shows as expected, that the highest stresses due to dead load are in the vicinity of gauges L1 and R1. Further, by using the formula $S = \varepsilon E$ for the values of strain measured at L1 and R1, we get

L1 = -82 μ in/in	R1 = -75 μ in/in
L2 = -15 μ in/in	R2 = -11 μ in/in
L3 = -8 μ in/in	R3 = -5 μ in/in
L4 = -44 μ in/in	R4 = -30 μ in/in
L5 = -31 μ in/in	R5 = -23 μ in/in
L6 = -16 μ in/in	R6 = -12 μ in/in
L7 = +25 μ in/in	R7 = +24 μ in/in
L8 = -12 μ in/in	R8 = -12 μ in/in

- ve readings indicate compression

+ ve readings indicate tension

Figure 10 Initial Strain Gauge Readings - Bus Unloaded

$$S_{L1} = (82 \times 10^{-6})\ (30 \times 10^{6})$$

$$= 2460 \text{ psi compression}$$

$$S_{R1} = (75 \times 10^{-6})\ (30 \times 10^{6})$$

$$= 2550 \text{ psi compression}$$

The left hand support arm is thus subject to slightly less stress than the right hand one due presumably to non-symmetry in the bus. The average of the two measured values however, is 2355 psi, which compares favourably to the theoretically calculated value of 2384 psi.

During the second series of tests, with the bus loaded and stationary, the increase in strain for both L1 and R1 gauges was found to be 16.7 μ in/in.

Once again calculating stress, we get

$$\Delta S = \Delta \varepsilon E$$

$$= (16.7 \times 10^{-6})\ (30 \times 10^{6})$$

$$= 501 \text{ psi compression}$$

This increase in stress from the unloaded to the loaded condition also agrees favourably with the theoretically calculated value of 480 psi.

The following section deals with strain values recorded during testing of the bus while loaded with passengers and moving on the road.

Typical strain outputs for gauges L1 and R1 are shown in Figure 11. Note a maximum deflection of +3 and -5 divisions which indicates corresponding strains of +25 μ in/in and -41.7 μ in/in. These values for strain when coupled with the initial dead load strain values of -82 μ in/in for L1 and -75 μ in/in for R1 yield values of -57 to -123.7 μ in/in for L1 and -50 to -116.7 μ in/in for R1. Stresses are therefore in the range of 1710 psi to 3711 psi compression in this area.

A typical strain output for R2 is shown in Figure 12. Note a maximum deflection of -10 divisions for a turning situation. The maximum deflections for gauges R2 and L2 were ±83.3 μ in/in strain. These values, coupled with the initial dead load strain value of -15 μ in/in for L2, yield a range of +68.3 μ in/in to 98.3 μ in/in, with stress values ranging from 2049 psi tension to 2949 psi compression.

Similarly, the ±83.3 μ in/in strain, coupled with the initial strain value of -11 recorded for R2, yields a range of +72.3 to -94.3 μ in/in, with stress values ranging from 2169 psi tension to 2829 psi compression.

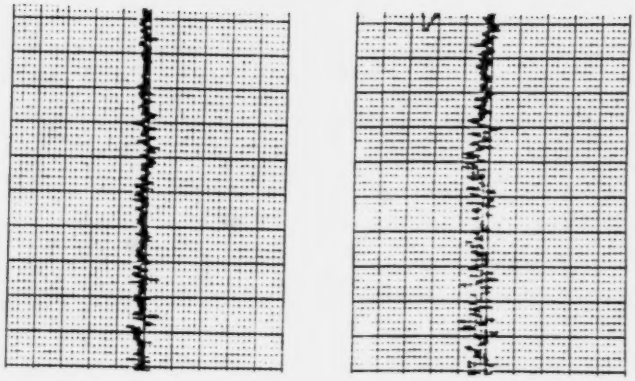


Figure 11 Strain Output for Gauges L1 and R1 - Bus Loaded

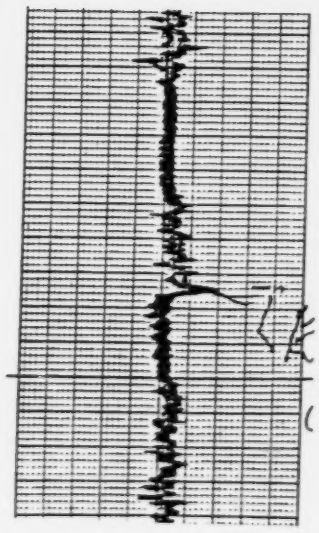


Figure 12 Strain Output for Gauge R2 - Bus Loaded

Figure 13 shows typical strain gauge outputs for gauges R2 and R8 for the test situation of backing the bus and using the automatic limiting device to stop the bus. This would apparently put very large strains on these areas of the support, but the strip chart results indicate that relatively small spikes occur the instant the bus is stopped. Note that these spikes do not exceed ±5 divisions. Therefore, these strain values, and hence, their stresses are not as significant as the stresses produced when the bus is moving along the highway at normal speeds.

It was noted that strain values for gauges L3, L4, L5, L6 L7, R3, R4, R5, R6, and R7 aiso yielded stress values below 4000 psi in tension or compression.

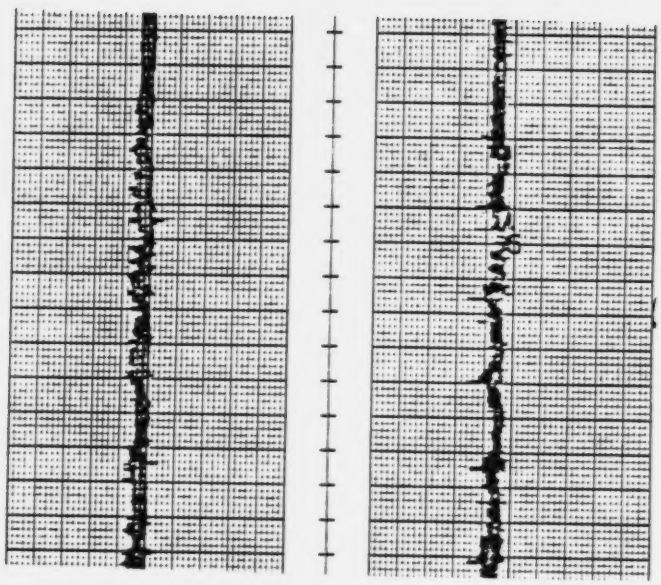


Figure 13 Strain Output for Gauges R2 and R8 - Stopping in Reverse

Note: Gauges produce 6mv per μ in/in
Chart recorder set at 50 mv/div (= 8.3 μ in/in)
∴ Major division ≈ 42 μ in/in

5. DISCUSSION OF RESULTS

As can be seen from the results of the static tests, there is good correlation between the values measured for stress at locations L1 and R1 and the theoretically predicted values for these locations. This gives us considerable confidence in the stress values measured during the on road tests.

During the on road tests with the bus loaded, many of the measured stresses oscillated rapidly between tension and compression. However, none of the stress levels exceeded 4000 psi. It is well known that materials fail under reversal of stress, at stresses smaller than the ultimate strength of the material under static loading conditions. This phenomenon of decreased resistance of a material to repeated stresses is called fatigue. The magnitude of the stress required to produce failure decreases as the number of cycles of stress increases. After stress is reduced beyond a certain level, however, failure will not occur regardless of the number of cycles of stress imposed on the material. This is called the endurance limit, and for structural steel with poor surface finishes, it is assumed to be close to 20,000 psi, when stresses are completely reversing and in the bending mode. Since all measured stress, at under 4000 psi, were well below the endurance limit, the structure in this area should not fail due to the cycled loading.

It is interesting to note, that if the boxed-in wide flange 4" x 4" support beam construction were changed to a simple box section similar to the original design, the cross sectional moment of inertia would decrease sufficiently such that the formula $S = Mc/I$ would predict stresses in excess of 25,000 psi for the same loadings. This is in excess of the endurance limit, and shows the magnitude of the effect which the modifications had on the strength of the articulating joint.

6. CONCLUSIONS

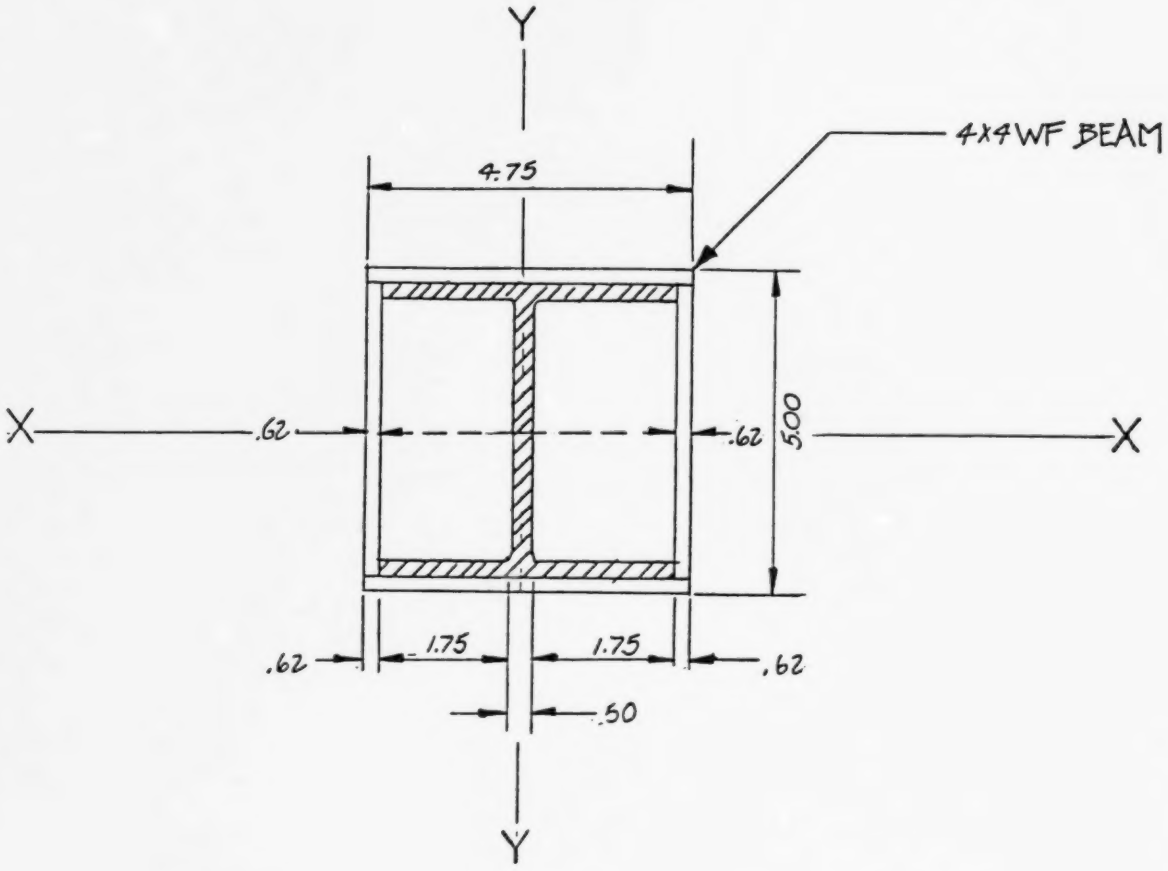
The failure of the structural members in the articulating joint of the Neoplan City Liner 116 intercity articulating bus was the result of cyclic stresses in excess of the endurance limit for the structural members and the design geometry used for the bus.

The modifications made to both the structural members themselves, and to the design geometry, have reduced stress levels to well below the endurance limit of the members in the area of the articulating joint. As a result, these members should not fail in normal service.

Appendix A

Calculation of Moment of Inertia

CROSS SECTION



$$I_{xx} \text{ for beam} = \frac{4 \times 4^3}{12} - 2\left[\frac{1.75 \times 3.5^3}{12}\right]$$

$$= 21.333 - 12.505$$

$$I_{xx} \text{ for box section} = \frac{4.75 \times 5^3}{12} - \frac{4 \times 4.25^3}{12}$$

$$= 49.479 - 25.589$$

$$\text{Total } I_{xx} = 21.333 - 12.505 + 49.479 - 25.589 = 32.718 \text{ in}^4$$

$$I_{yy} \text{ for whole section} = \frac{5 \times 4.75^3}{12} - 2\left[\frac{4.25 \times 1.75^3}{12} + 4.25 \times 1.75 \times 1.125^2\right]$$

$$= 44.654 - 2\left[1.898 + 9.413\right]$$

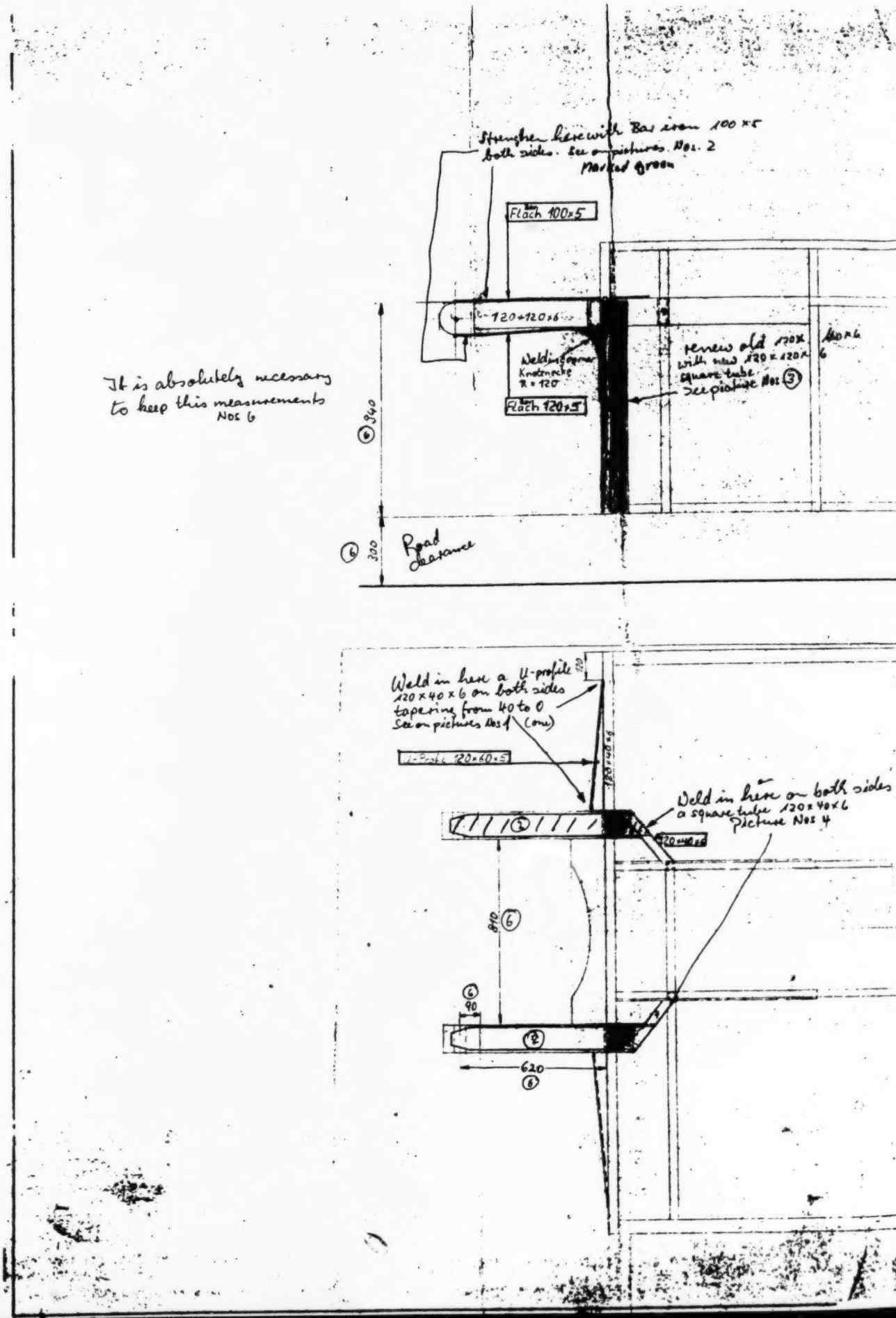
$$= 44.654 - 22.622$$

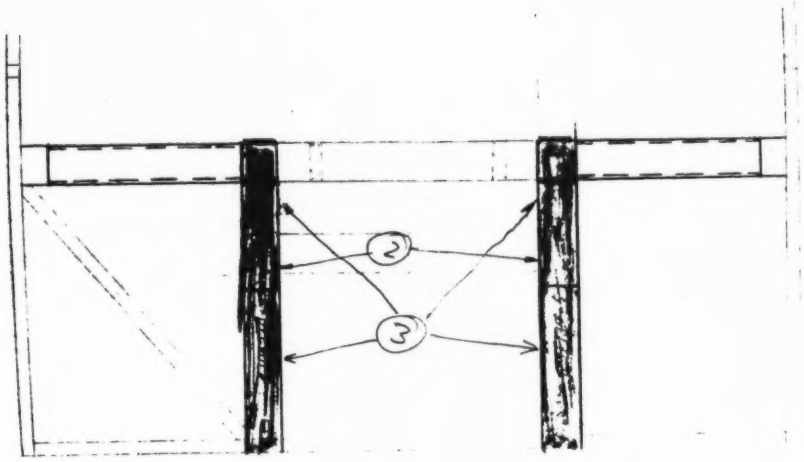
$$\text{Total } I_{yy} = 22.032 \text{ in}^4$$

Appendix B

Modification Drawings

Supplied by Neoplan


Strengthen here with Bar iron 100×5
both sides. See on pictures Nos. 2
Marked green
Flach 100×5
L-120×120×6
Welding seam
Kehlnaht
a = 120
Flach 120×5
renew old 120×
with new 120×120×
square tube
See picture Nos 3
940
300
Road clearance
It is absolutely necessary
to keep this measurements
Nos 6
Weld in here a U-profile
120×40×6 on both sides
tapering from 40 to 0
See on pictures Nos 1 (one)
U-Profile 120×60×5
Weld in here on both sides
a square tube 120×40×6
Picture Nos 4
120×40×6
910
90
620

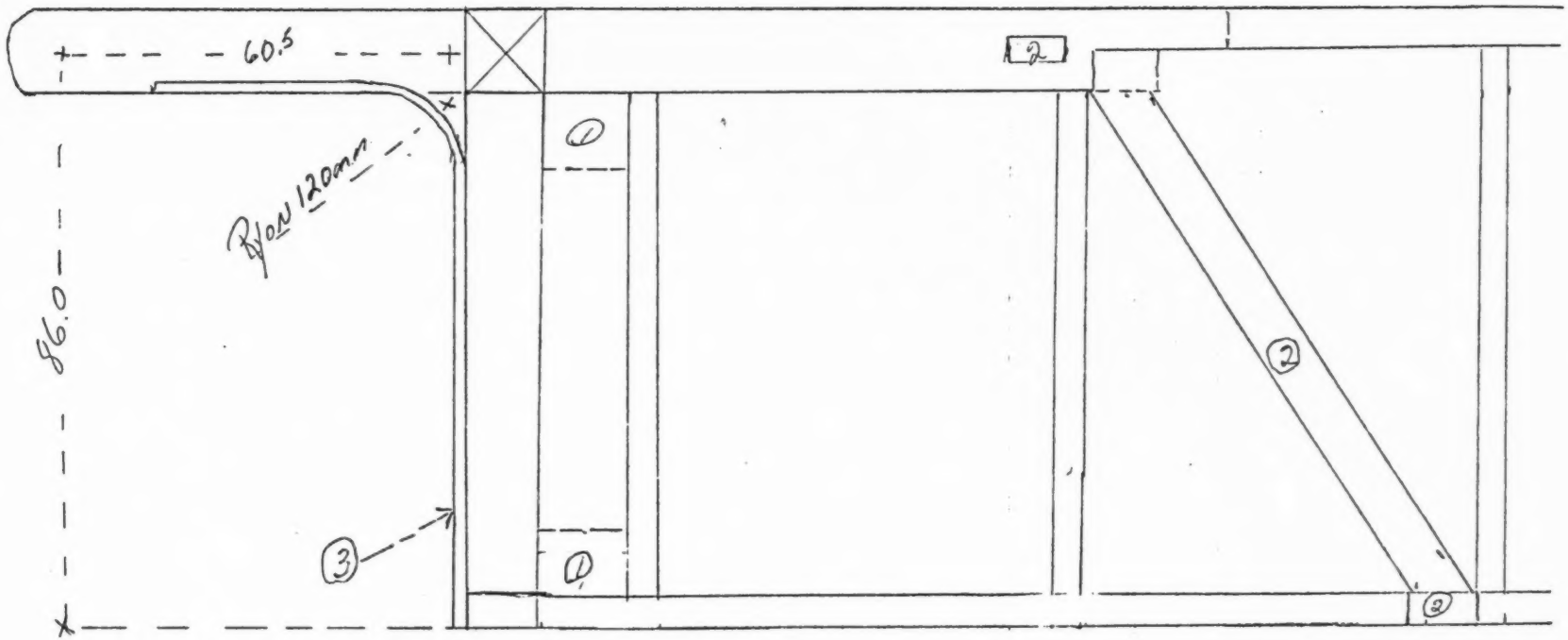


Please note, all measurements are in mm (milimeter)
- the red drawn in pices are additional or stronger material
- the welder must be a top craftsman as this are safety parts

	1982 Tag Name: 13.4. Gfrörer	Ohne unsere Genehmigung darf diese Zeichnung weder kopiert noch vervielfältigt noch an Dritte weitergegeben werden	NEOPLAN BOTTLOB AUWÄRTER KG STUTTGART-MÖHRINGEN
	Maßstab: 1:10	Benennung: Alternativ Artikulation Umbau Gelenkaufnahme N 120 Ausf. Kanada	Zeichnungs-Nr.: 2 6 4 3 4
	Änderungsindex:		Ersatz für:

Appendix C

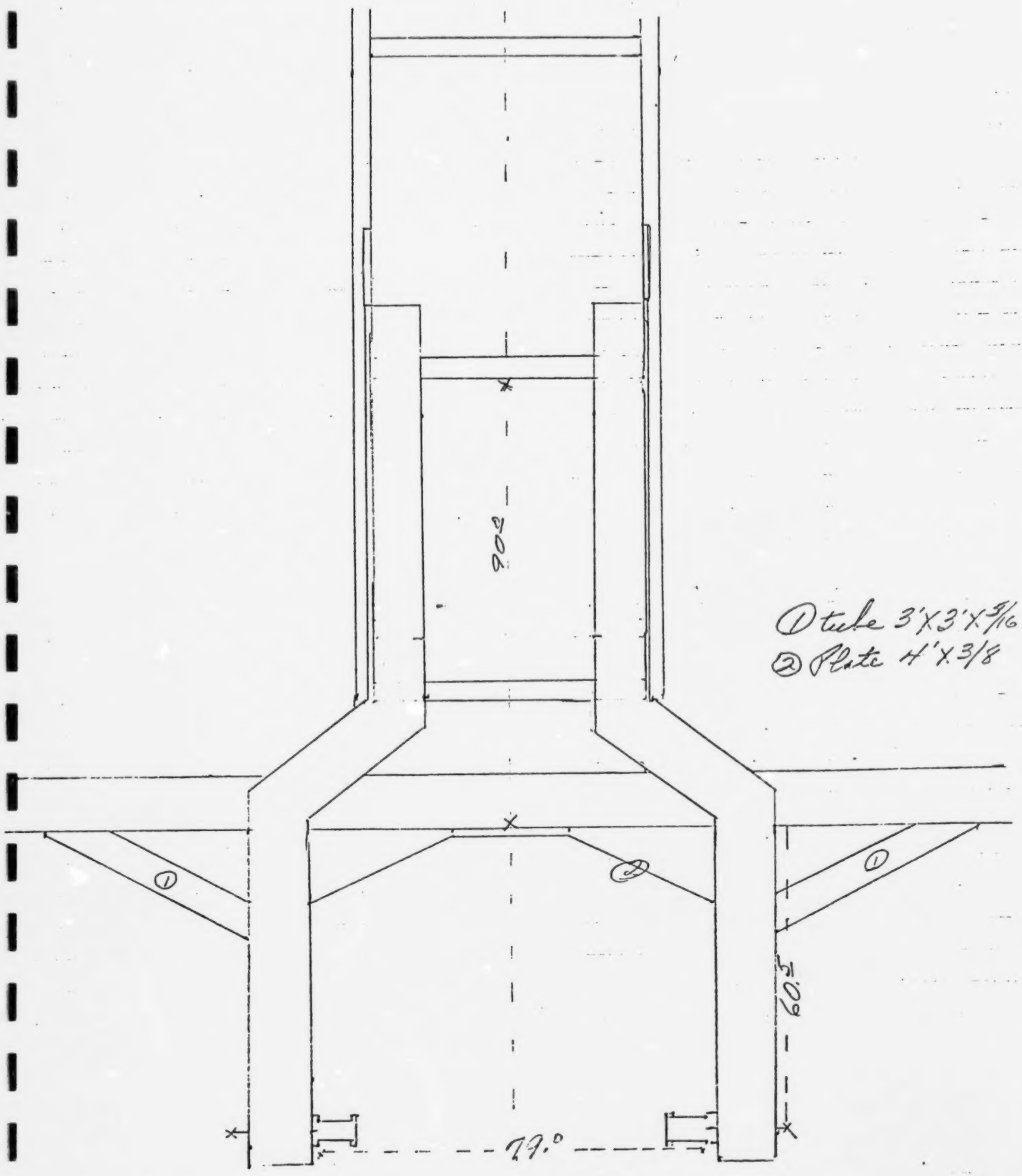
Modification Drawings
As Performed by Voyageur

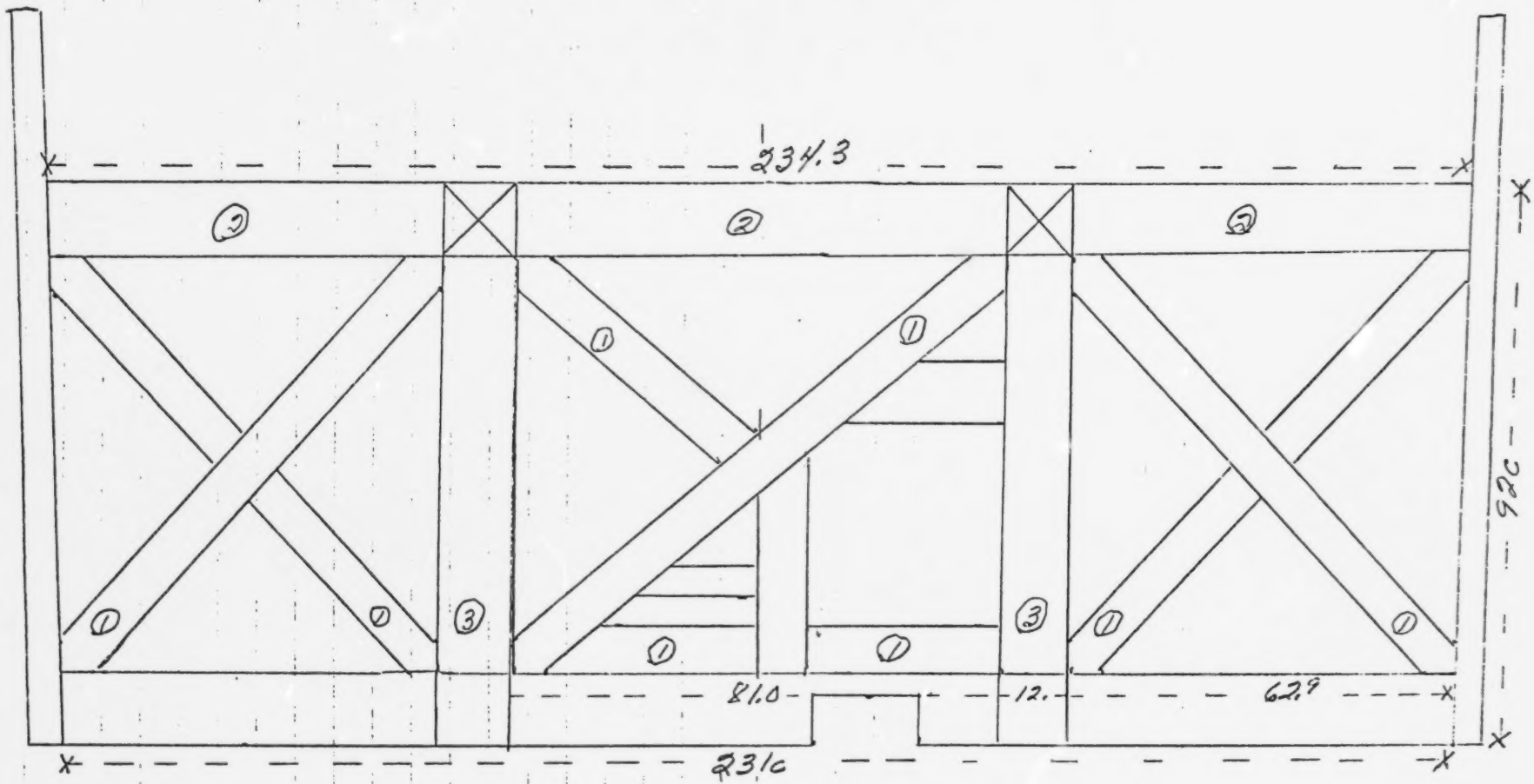


① Plate 4" X 3/8

② Tube 3' X 1½ X 1/8

③ Plate pleine longueur 1 1/2 X 3/8


20.0
60.5
79.°
① tube 3'X3'X 3/16
② Plate 4'X 3/8



① Tube 3" x 1½ x ⅛

② I Beam 4" x 4" Plate 4" x ⅜ 1 each

③ I Beam 4" x 4" Plate 4" x ⅜ 2 each face Plate 4½ x ⅜

1 x 10

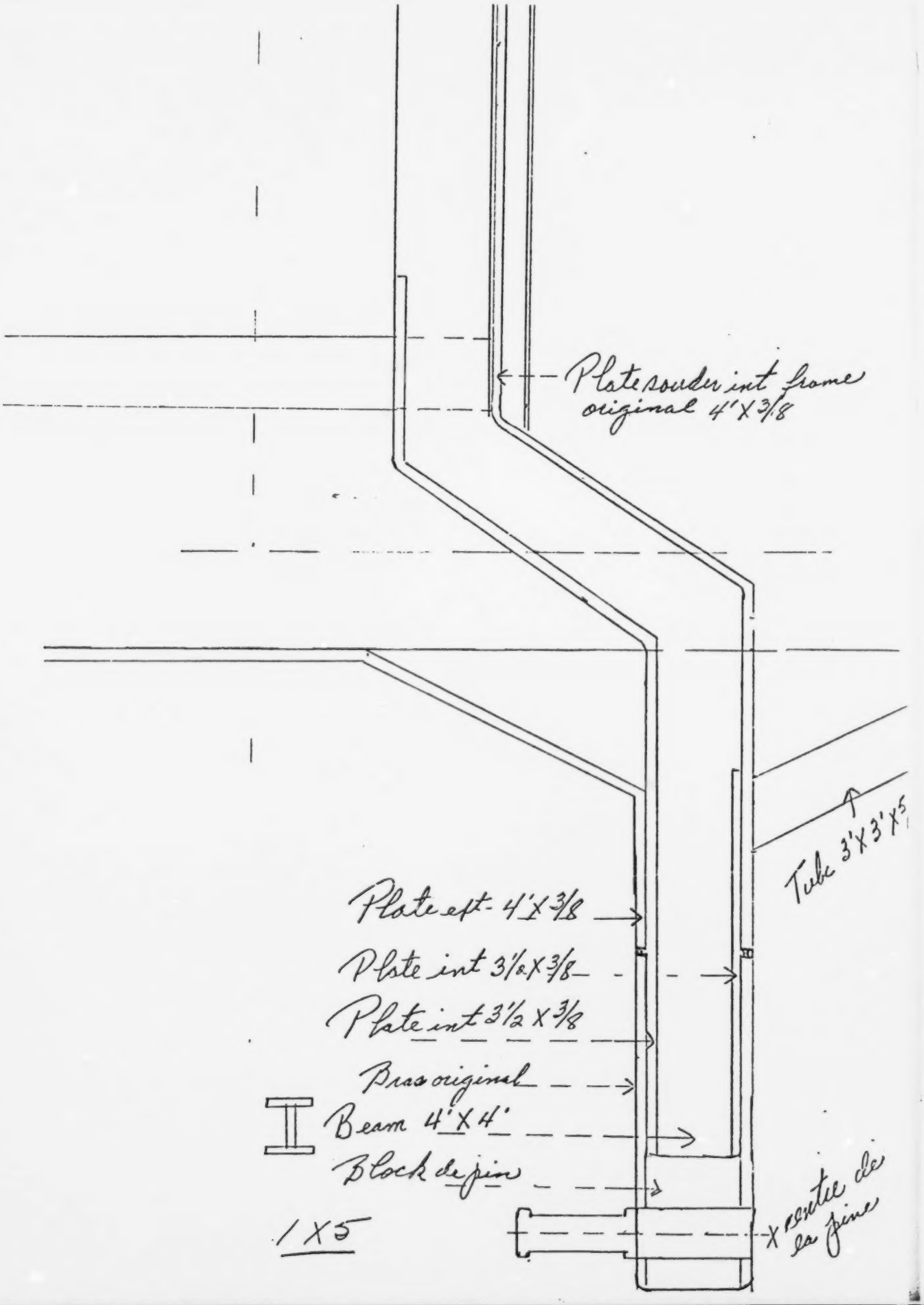


Plate souder int frame
original 4'X3/8
Tube 3'X3'X5
Plate ext- 4'X3/8
Plate int 3½X3/8
Plate int 3½ X3/8
Bras original
Beam 4'X4'
Block de pin
1X5
X centre de la pine

Appendix D

Metric Conversion Factors

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10 000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F